REHABILITATION OF WATER-DAMAGED RUNWAY COMPOSITE PAVEMENTS

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INTRODUCTION

Although Runway A of Narita International Airport has a length of 4,000 m, 3,250 m of it have been used for both aircraft landings and takeoffs, the south end remaining unused for the landings. As the full length of the runway is now to be used, it was necessary to perform a detailed inspection and fix deteriorated parts of this section. As the last 150 m of this section was located in the route which aircraft would precede into the runway from an exit taxiway, it had to be repaved to give it a more durable structure.

The composite pavement consisting of an asphalt mixture layer placed on continuously reinforced concrete slabs over the subbase was constructed at the end of Runway A in Narita International Airport between the autumn of 2011 and spring of 2012. However, several months after it had been opened to traffic, some signs of distress appeared on the pavement surface. These included a dull sound when subjected to a hammer tapping test, white spots and black spots on the surface, stains at construction joints and flows of asphalt mixture around airport lights.

Along with conducting tentative repairs, a permanent rehabilitation method has been studied. The causes of the above problems were studied in several different ways, including examination of the construction records, investigation of the site, laboratory tests, numerical analysis and literature survey. The causes can be classified into two kinds, namely, intrusion of water into asphalt mixtures and low stability of the asphalt mixtures.

Based on these studies, rehabilitation work in which the existing asphalt mixture layers are removed and new asphalt mixture layers are placed with some special treatments for water drainage has been planned. A new asphalt mixture layer that is composed of two kinds of polymer modified asphalt layers is to be introduced. Two kinds of water drainage facilities are to be installed on concrete slabs surrounding the rehabilitation area to remove water from the asphalt mixtures.

STRUCTURE OF EXISTING COMPOSITE PAVEMENTS

As the end of the runway is part of the route by which aircraft will precede onto the runway from the exit taxiway, the pavement is required to possess a more durable structure. In the past, a continuously reinforced concrete pavement was employed in the ends of the runways in Narita International Airport. However, a composite pavement consisting of asphalt mixture layers placed on concrete slabs was used this time, in order to ensure ease of repair for the asphalt mixture layers in the future.

A plan and typical cross sections of the existing pavement are shown in Figure 1 and Figure 2. The composite pavements were used in the central trafficked portion of the runway and the continuously reinforced concrete pavements were used in the outer portion. The composite pavements were also used in the segment connecting the runway with one of the exit taxiways. Continuously reinforced concrete slabs were adopted for these concrete slabs. The asphalt mixture layer was surrounded by concrete slabs at the bottom and concrete pavements along the circumference. The structure of the composite pavement is a 100 mm thick asphalt mixture layer, constituting a surface course and a binder course, on top of a 350 mm thick continuously reinforced concrete slab. The surface course was composed of a 50 mm thick dense graded asphalt mixture layer, and the binder course was composed of a stone mastic asphalt mixture also 50 mm in thickness. Since Runway A is one of the main runways, the plan was to perpetually ensure the structural durability of its pavement with concrete slabs and repair the asphalt mixture layer as necessary when any distress was discovered.

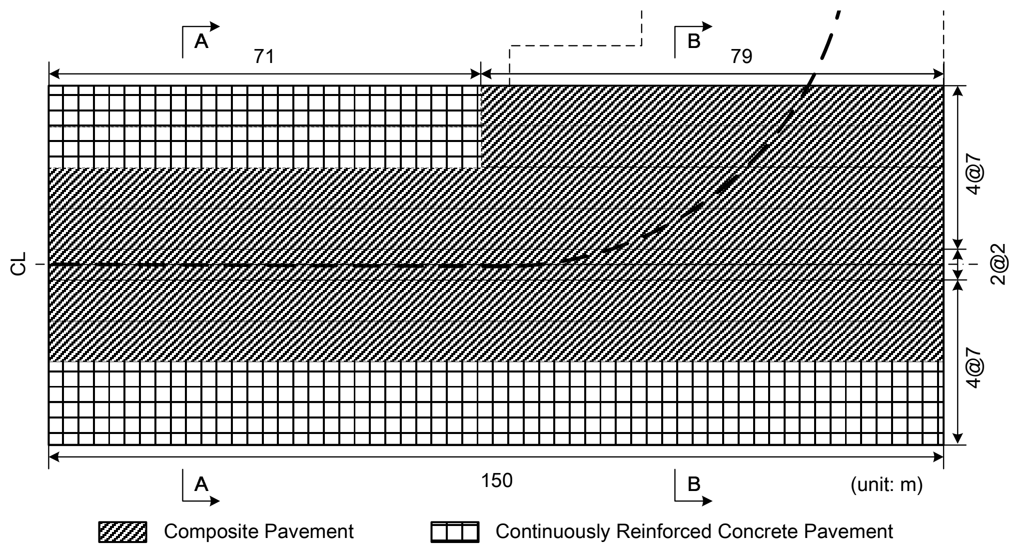
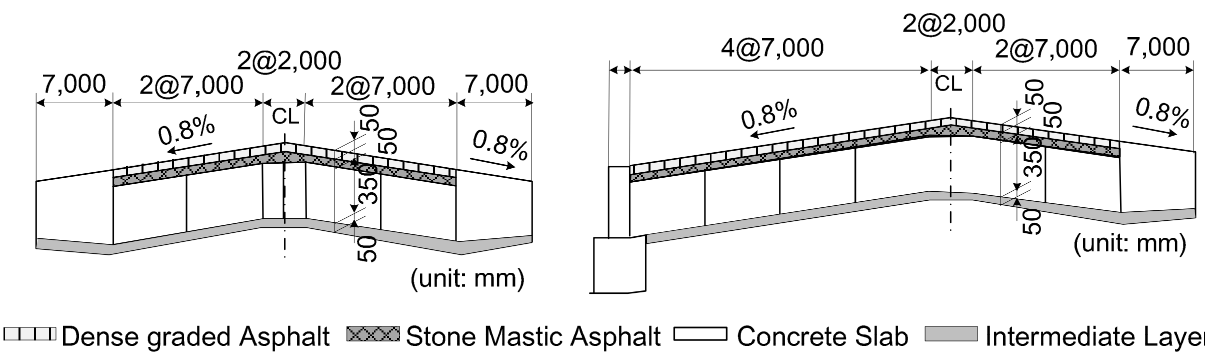


Figure 1. Plan View of Pavements at End of Runway.



a) Cross Section A – A. b) Cross Section B – B.

Figure 2. Typical Cross Sections of Pavements at End of Runway.

The composite pavement was constructed in accordance with a construction guide for airport pavements (Civil Aviation Bureau [1]) between autumn of 2011 and spring of 2012. The quality of the materials, including the asphalt mixtures and emulsified asphalt tack coats, was approved according to the specifications and the pavements were used for aircraft operations starting in April 2012.

SIGNS OF DISTRESS FOUND ON COMPOSITE PAVEMENT SURFACE

Several signs of distress were found on the composite pavement a few months after being opened to traffic as shown in Figure 3. The conditions of the distress were often surveyed ever since then and the results are briefly described below.

- Dull sound when subjected to hammer tapping tests
  Found mostly in locations where aircraft landing gear passes.

- Black spots
  Found in the central area of the runway.

- White spots
  Found throughout the entire section.

- Stains at construction joints
  Found at construction joints of the surface course.

- Flow of asphalt mixtures around lights
  Found in the segment connecting the exit taxiway where an aircraft nose gear passes.

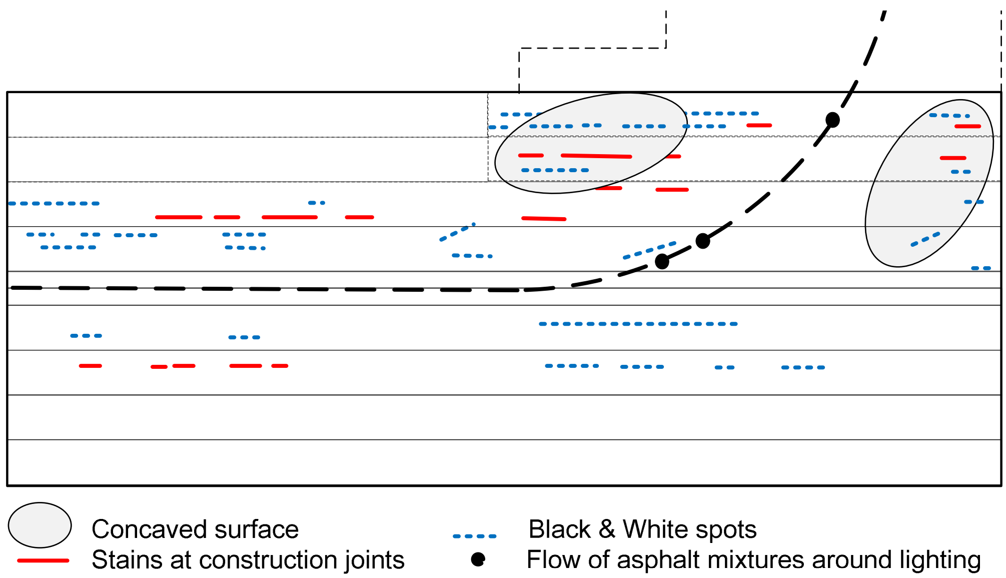


Figure 3. Signs of Distress Found on Composite Pavement Surface.

STUDY ON CAUSES OF MAJOR SIGNS OF DISTRESS

The following investigations were conducted to study the causes of signs of distress found at the end of the runway.

- Structural analysis using 3D-FEM
  The response of composite pavement to aircraft loads was analyzed by using 3D-FEM.

- Quantification of characteristics of core samples
  Various properties were measured by taking core samples from the asphalt mixtures. As the distressed areas which had been tentatively repaired were subsequently damaged again, core samples were taken from these areas and their properties were examined.

- Chemical analysis of core samples
  To identify the chemical composition of the black spots, white spots and stains at

construction joints, several kinds of chemical analyses were conducted.

STRUCTURAL ANALYSIS OF COMPOSITE PAVEMENT USING 3D-FEM

Outbound international aircraft with large masses turned onto the end of the runway from the taxiway. 3D-FEM was used to investigate the response of composite pavement to such load conditions (Nishizawa [2]).

Modeling of Composite Pavement and Conditions of Analysis

The composite pavement was modeled as shown in Figure 4.

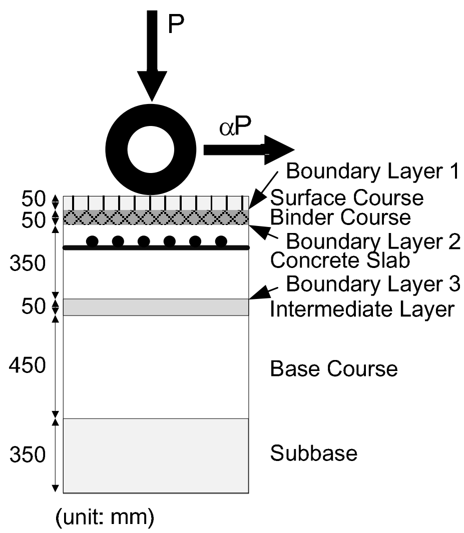


Figure 4. Pavement Structure Model.

To take into account the difference in temperature in the thickness direction of the asphalt mixture layer, an elastic modulus of the asphalt mixture can be separately assigned to the surface course and binder course. Boundary layers composed of a group of vertical springs and horizontal springs were introduced to consider the bonding condition at the interface between the surface course and binder course, and at other interfaces. The following three analytical models were considered on the surface course, binder course and boundary layer between them.

- CASE 1
  The surface course and binder course have the same elastic modulus. These two courses were fully bonded.

- CASE 2
  The surface course has a smaller elastic modulus than the binder course has, which models the summer condition. These two courses are fully bonded.

- CASE 3
  The surface course has a smaller elastic modulus than binder course has. These two courses are completely separated.

The elastic modulus and spring constants assigned to the models are described in Table 1.

Poisson's ratio for the concrete slab is set to 0.2 and the others are set to 0.35. The upper and lower layers other than the surface course and binder course were modeled as being fully bonded.

Table 1.
Elastic Modulus of Layers and Spring Constants of Boundary Layers.

Item	Layer	CASE 1	CASE 2	CASE 3
Elastic Modulus (MPa)	Surface Course	500	500	500
	Binder Course	500	1,000	1,000
	Concrete Slab	30,000	30,000	30,000
	Asphalt Intermediate Layer	5,000	5,000	5,000
	Base Course	3,000	3,000	3,000
	Subbase	500	500	500
	Subgrade	80	80	80
Spring Constant (MN/m^3)	Boundary Layer 1, Horizontal	100,000	100,000	10
	Boundary Layer 1, Vertical	100,000	100,000	100,000
	Boundary Layer 2, Vertical & Horizontal	100,000	100,000	100,000
	Boundary Layer 3, Vertical & Horizontal	100,000	100,000	100,000

The B747-400 was adopted as the aircraft load, being representative of actually operated aircraft. In each case, three combinations of vertical loads and horizontal loads were used; that is, no horizontal load, small horizontal load and large horizontal load. A ratio of horizontal load to vertical load α, shown in Figure 4, is 0.00, 0.25, 0.50, respectively.

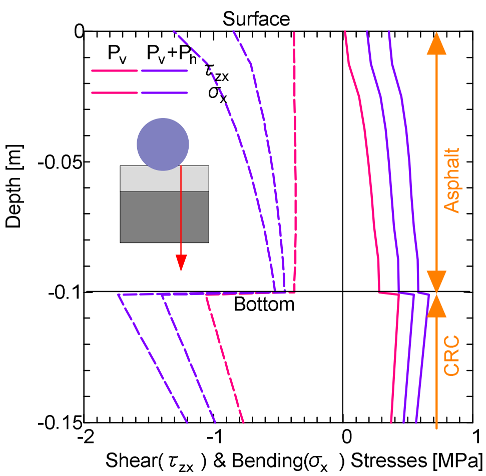
In consideration of the symmetry of the pavement structure and loading condition, the calculation was carried out for only half of the model.

Results of Analysis

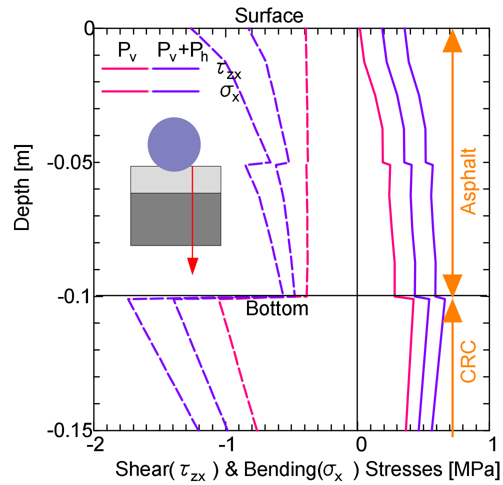
The results of calculation for both the shear stress and bending stress in the asphalt mixture layer are described in Figure 5. This figure shows the distribution of those stresses at a wheel edge throughout the thickness.

In all cases, both the shear stress and bending stress increase as the horizontal load increases. In CASE 1, the continuity of both stresses is observed between surface course and binder course, thus there is little risk of separation between the two layers as long as the bonding strength at this interface is secured. However, there might be higher risk of separation between the asphalt mixture layer and concrete slab as the stress at the interface between them is far larger than that between the asphalt mixture layers. This is the same as when the elastic moduli differ between the surface course and binder course, that is, in CASE 2.

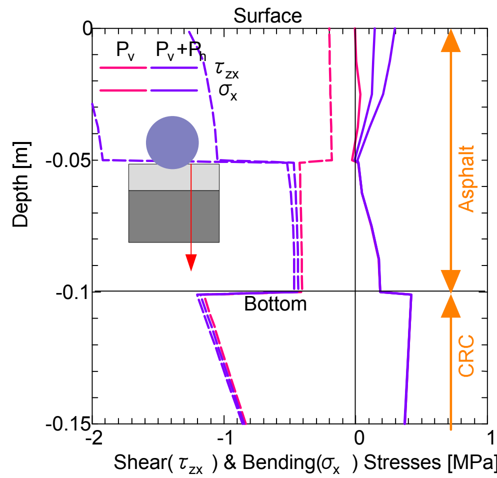
Contrarily, in CASE 3 where the bonding strength between the surface course and binder course is smaller, the shear stress both at the interface and in the surface course increases as the horizontal load increases.



a) CASE 1.



b) CASE 2.



c) CASE 3.

Figure 5. Shear Stress and Bending Stress of Asphalt Mixture Layer throughout the Thickness.

CHARACTERISTICS OF THE ORIGINAL ASPHALT MIXTURES

The test results of the cores extracted from the original asphalt mixture layer are summarized as follows:

- Fracture of asphalt mixtures
  Some cores taken from an area with dull sound response as a result of hammer tapping tests were horizontally separated into two parts. The separated position was not the interface between two layers, but within the surface course (30–40 mm from the pavement surface). The bond between the binder course and concrete slab was firmly established.

- Thickness
  The thicknesses of the cores taken from the sound area for both the surface course and binder course conformed to the standard. In the area with the dull sound, the thickness of the binder

course was almost uniform and conformed to the standard, but the surface course was thin in some cores.

- Degree of compaction
  The degrees of compaction of the cores taken from both the dull sounding areas and the sound areas satisfied the specification. The degree of compaction of the surface course and binder course in the sound areas was 101.0% and 99.5% respectively, and the average of the dull sounding areas was 100.9% and 99.7% respectively.

- Air void
  Air voids of the cores had decreased from those taken at the time of construction. In particular, the decrease in the asphalt mixtures of the surface course was significant. The air voids of the surface course and binder course in the sound areas were 2.1% and 2.9% respectively, and the average of the dull sounding areas was 2.1% and 2.8% respectively.

- Compressive strength
  There were no differences in the cores taken from the dull sounding areas and the sound areas. The compressive strength of the surface course and binder course in the sound areas was 1.10 MPa and 0.91 MPa respectively, and the average of the dull sounding areas was 1.12 MPa and 1.02 MPa respectively.

- Aggregate gradation and asphalt content
  No differences were found in aggregate gradation and asphalt content of the cores taken from the dull sounding areas and the sound areas.

- Characteristics of asphalt
  The surface course was more aged than the binder course irrespective of the area (dull sounding and sound). As shown in Table 2, the asphalt mixtures in the dull sounding areas were much more aged than those in the sound areas.

Table 2.
Properties of Asphalt Extracted from Cores.

Item	Cores in Sound Area		Cores in Dull Sounding Area		Original
	Surface Course	Binder Course	Surface Course	Binder Course	
Penetration (1/10 mm)	48	57	41	56	72
Softening Point (°C)	50.5	48.5	52.5	48.5	47.5
Ductility (cm)	56	100+	25	100+	100+

- Flow of asphalt mixtures around airport lights
  In the curved area of the taxiway, flows of asphalt mixtures were found not only around airport lights but also away from the lights. Therefore, the flow is most likely caused by the insufficient ability of the asphalt mixtures to carry the aircraft load.

CHARACTERISTICS OF ASPHALT MIXTURES USED FOR TENTATIVE REPAIRS

Test results of the cores taken from the asphalt mixtures placed during tentative repair work are summarized as follows:

- Fracture of asphalt mixtures
  Marks of slippage between the asphalt mixture layer and concrete slab were found in the cores taken from the dull sounding areas.

- Water
  In almost all cores, some water was found at the interface between the asphalt mixture layer and concrete slab. In areas with blistering and dull sounding areas, horizontally fractured planes were found 20–40 mm from the surface. Moreover, other fractured planes were also found at the interface between the surface course and binder course in areas where water seeps out. Water was observed in these fractured planes. The water content of the asphalt mixture is shown in Table 3. The water content of asphalt mixtures in dull sounding areas was three times as large as that in sound areas.

Table 3.
Water Content of Asphalt Mixtures.

Area	Water Content (%)		Air Void (%)	
	Surface Course	Binder Course	Surface Course	Binder Course
Water Seep-out	0.41	0.83	1.8	3.3
Blistering	0.44	0.65	1.9	3.2
Dull Sounding	0.43	0.81	2.3	3.5
Sound	0.16	0.26	2.3	2.2

- Thickness
  Many concave surfaces were observed in the dull sounding areas. The thickness of the asphalt mixtures in both the surface course and binder course had decreased from the designed thickness. The average thickness of the surface course and binder course was 33 mm and 40 mm respectively.

- Air void
  The amount of air voids in the asphalt mixtures had decreased from the design in both the sound areas and the dull sounding areas. The amount of air voids in the surface course and binder course in the sound areas was 0.8% and 1.8% respectively, and in the dull sounding areas 1.6% and 2.4% respectively (at minimum).

- Dynamic stability of surface course asphalt mixtures
  Table 4 shows the dynamic stability of the asphalt mixtures taken from the surface course as core samples 200 mm in diameter. The dynamic stability (DS) satisfied the DS > 300 times/mm specification (Suzuki and Tanaka [3]).

Table 4.
Dynamic Stability of Surface Course Asphalt Mixtures.

Item		Sound Area		Dull Sounding Area	
Thickness (mm)		50	51	25	26
Air Void (%)		1.4	1.7	2.8	2.1
Dynamic Stability	Core	550	610	680	1,280
(times/mm)	Adjusted	413	458	510	960

CHEMICAL ANALYSIS OF CORE SAMPLES

The composition of the black spots, white spots and stains at construction joints were analyzed using Fourier transform infrared (FT-IR) analysis, gas chromatography-mass spectrometry (GC-MS) and gel permeation chromatography (GPC). The samples for these analyses were taken from the surface and inside of the asphalt mixtures. The results are summarized below.

- Black spots
  Black spots were recognized as being composed of the same substances as asphalt emulsion and straight asphalt.

- White spots
  White spots were recognized as inorganic and contained calcium carbonates. There were no obvious differences in the asphalt mixtures at the fractured planes and others.

- Stains at construction joint
  Stains at construction joint were made of the same substances as the white spots.

DISCUSSION ON CAUSES OF MAJOR SIGNS OF DISTRESS

In consideration of the above facts, the causes of signs of distress found in the composite pavement are summarized as follows:

Dull sound at hammer tapping tests

The dull sound heard at hammer tapping tests is thought to derive from the following two factors: fractures in the asphalt mixtures and separation of the upper and lower layers.

It is clear from the results of 3D-FEM that the separation between the asphalt mixture layers is caused when the bonding strength between two layers is too small and the strength of surface course asphalt mixtures is also too small.

It is also clear from the laboratory tests that there are no differences in the mechanical properties of the asphalt mixtures taken from the dull sounding areas and the sound areas. In the recently revised airport pavement design guide (Civil Aviation Bureau [4]), polymer modified asphalt mixtures are specified as the standard for use as surface course to secure longer pavement lives and DS > 2,500 times/mm is prescribed for Runway D of Tokyo Haneda International Airport. In addition, the air voids in asphalt mixtures were found to be below the standard. Thus, the insufficient stability of asphalt mixtures is assumed to be one of the causes of this sign of distress.

Moreover, it was found that some water remained in the asphalt mixtures and the amounts in both dull sounding areas and areas where water seeps out on the pavement surface were higher than that in the sound areas. It is said that water remaining in asphalt mixtures evaporates with a rise in temperature and generally disappears. It is estimated from the results of the tests on the cores that a coefficient of permeability of asphalt mixtures decreases to 10^{-10} cm/s as the air voids is about 2% (Sasakawa and Okada [5]). This might cause the blistering in the asphalt mixture layers if the water remains inside (Hao and Hachiya [6]). When aircraft loads are applied to the pavement area in which the delamination between layers is caused by blistering, slippage and significant unevenness may appear on the pavement surface. Several reasons for water remaining in the asphalt mixture can be given including infiltration of rainwater from construction joints, the presence of water when the asphalt mixtures were laid, supply of moisture from concrete slabs, and so on. These reasons, however, could not be ascertained until now.

As it is impossible to reduce the horizontal load of aircraft, improvement of the pavement structure such as strengthening of asphalt mixtures and increase of bonding strength at the interface will be required, along with the introduction of measures for removing water from the pavement.

Black spots, white spots and stains at construction joints

The causes of the signs of distress found on the pavement surface such as black spots, white spots and stains at construction joints, will be explained below. These phenomena are, however, not directly connected with damage to the pavement.

Black spots were recognized as being composed of the same substances as those of asphalt emulsion and straight asphalt. Asphalt stains were also found on the fractured plane of cores with black spots. Therefore, asphalt might possibly exfoliate from aggregates in some segments.

White spots and stains at construction joints were found on the surfaces of areas where water seeped out from the inside, while they did not exist in asphalt mixtures. Therefore, efflorescence might be coming from the concrete slabs.

Flow of asphalt mixtures around airport lights

The flow of asphalt mixture surrounding airport lights is caused by the insufficient dynamic stability of asphalt mixtures, as mentioned above.

SUMMARY OF CAUSES OF MAJOR DISTRESS

Of the five types of distress signs, black spots, white spots and stains at construction joints are obviously harmless from the viewpoint of pavement structure. However, the dull sound heard at hammer tapping tests and the flow of asphalt mixtures will lead to serious structural damages. Their causes are summarized as follows:

Intrusion of water into asphalt mixtures

The composite pavement at the end of Runway A had a structure in which asphalt mixtures were laid on continuously reinforced concrete slabs. The stone mastic asphalt with high water tightness was used for the surface course and the dense graded asphalt mixture with low air voids for the binder course. In addition, the asphalt mixtures were surrounded by concrete on the bottom and all sides. Therefore, once water has permeated the pavement, it cannot naturally escape from it.

Low stability of asphalt mixtures

The stability of asphalt mixtures was insufficient to carry heavy aircraft loads, even though it met the standard of DS > 300 times/mm, because most international outbound aircraft used the end of the runway. Insufficient stability of the asphalt mixture resulted in plastic deformation progressed by the repeated application of aircraft loads.

REHABILITATION PLAN

Based on the above study, rehabilitation work, in which the existing asphalt mixture layers are removed and new specially treated asphalt mixture layers are placed, has been planned. Following are the major items that have actually been adopted.

Countermeasures against Intrusion of Water into Asphalt Mixtures

It is necessary to take measures on the assumption that the pavement has a structure in which water remains.

Pavement structure

The pavement structure will be such that the surface course is made of dense graded asphalt mixtures 60 mm thick and the binder course is made of drainage asphalt mixtures 40 mm thick. In order to ensure durability in the midst of heavy aircraft loads, 60 mm is required as the thickness of the surface course. Tack coat using polymer modified asphalt is also required on both the binder course and concrete slabs to secure the bonding strength at the interfaces.

From the viewpoint of blistering protection for the surface course, 4.5% is required as the air voids in order for water to evaporate when the temperature rises, and polymer modified asphalt is required in order for the amount of air voids at construction to be maintained after the runway has been opened to traffic. For the binder course, a drainage asphalt mixture with polymer modified asphalt and aggregates with a maximum particle size of 13 mm are adopted to guarantee that infiltrated water will be able to drain away through the binder course. The target amount of air voids is set at 20%.

Water draining facilities

Two kinds of water drainage facilities are built into concrete slabs around the rehabilitation area. One is transverse open grooves 6–10 mm in width to drain out water transversely and encourage evaporation, and the other is wider ditches filled with a drainage asphalt mixture to mainly drain out water longitudinally. The plan view is shown in Figure 6.

Countermeasures against Flow of Asphalt Mixtures

It is necessary to improve the mechanical properties of asphalt mixtures as a countermeasure for the flow of asphalt mixtures surrounding airport lights. It is required, as an actual measure, to increase the dynamic stability to improve the flow resistance of asphalt mixture; that is, an asphalt mixture with DS > 3,000 times/mm is required, in consideration of the fact that DS > 2,500 times/mm was adopted for Runway D of Tokyo Haneda International Airport (Hachiya, et al. [7]), and DS > 3,000 times/mm is specified for roads with one-directional daily traffic volume of more than 3,000 vehicles (Japan Road Association [8]).

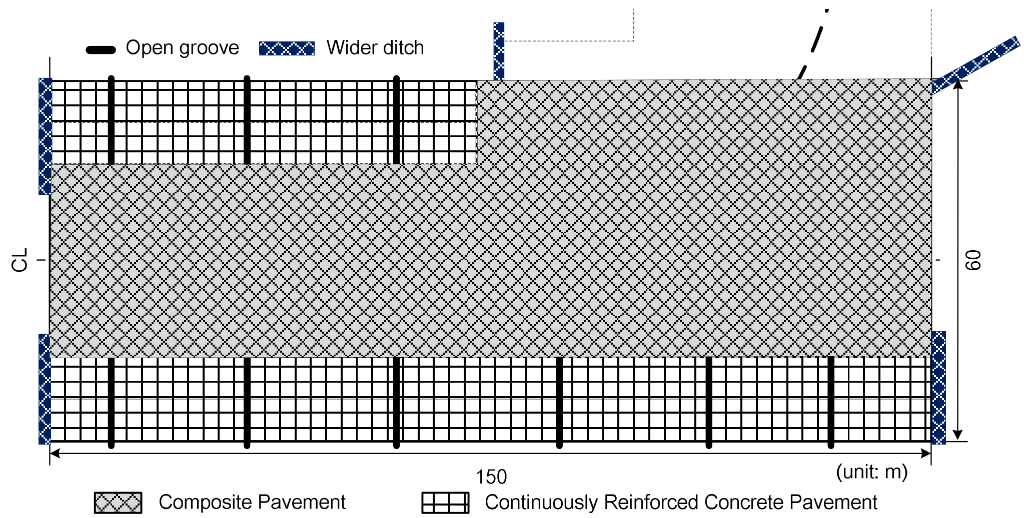


Figure 6. Plan View of Rehabilitation Area.

In order to meet this requirement, PMA (polymer modified asphalt) Type II is adopted for the surface course dense graded asphalt mixture and PMA Type H, which has higher viscosity, for the binder course drainage asphalt mixture (Japan Road Association [8]). Table 5 shows the specification of the above polymer modified asphalts.

Table 5.
Specification of Polymer Modified Asphalts.

Item	Straight (40–60)	PMA II	PMA H
Softening point (°C)	47–55	> 56.0	> 80.0
Ductility at 15°C (cm)	> 10	> 50	-
Toughness at 25°C (Nm)	-	> 8.0	> 20
Tenacity at 25°C (Nm)	-	> 4.0	-

Specification of Asphalt Mixtures for Rehabilitation Area

The following specifications apply to the asphalt mixtures. Table 6 shows the specification on aggregate size gradation and characteristics of asphalt mixtures.

Table 6.
Specifications for Asphalt Mixtures.

a) Aggregate Size Gradation.

Sieve Size (mm)	Passing (%)	
	Surface Course	Binder Course
26.5	100	-
19.0	95–100	100
13.2	75–90	90–100
4.75	45–65	11–35
2.36	35–50	10–20
0.6	18–30	-
0.3	10–21	-
0.15	6–16	-
0.075	4–8	3–7

b) Characteristics of Asphalt Mixtures.

Item	Surface Course	Binder Course
Stability (kN)	> 8.8	-
Flow (mm)	20–40	-
Air Voids (%)	3–6	-
Residual Stability (%)	> 75	-
Dynamic Stability (times/mm)	> 3,000	> 3,000
Stripping Ratio in Immersion Wheel Tracking Test (%)	< 5	-
Permeability (cm/s)	-	> 10^{-2}

Surface course

For the surface course, dense graded asphalt mixture with polymer modified asphalt (Type II) and aggregates with a 20 mm maximum particle size are used. New specifications on the amount of air voids (4.5%) and dynamic stability (3,000 times/mm) are added.

Binder course

For the binder course, drainage asphalt mixture with polymer modified asphalt (Type H) and aggregates with a 13 mm maximum particle size are used. New specifications on permeability (1 × 10^{-2} cm/s) and dynamic stability (3,000 times/mm) are added. The target amount of air voids is set to 20% to endure the permeability.

CONCLUDING REMARKS

Several signs of distress such as a dull sound at hammer tapping tests, black spots, white spots, stains at construction joints and flow of asphalt mixtures around airport lights have been found on the composite pavement of the end of Runway A of Narita International Airport a few months after it was opened to traffic. Of the above, the dull sound at hammer tapping tests and flow of asphalt mixtures were recognized as serious distress. Their causes are summarized as follows:

- Water remaining in composite pavement

The composite pavement had a structure in which dense graded asphalt mixture with low air voids and stone mastic asphalt with high water tightness were placed on continuously reinforced concrete slabs, and the asphalt mixtures were surrounded by concrete on the bottom and all sides. Therefore, once water permeated the asphalt from the outside, it was hard for it to naturally escape to the outside, which led to fractures in the asphalt mixtures and delamination of asphalt mixture layers.

- Flow of asphalt mixtures around airport lights

Although the asphalt mixture used met the standard of DS > 300 times/mm, it does not meet new standard recently revised from the viewpoint of durability against aircraft loads. This low durability led to severe plastic deformation in areas where aircraft pass repeatedly.

Rehabilitation methods for solving the above problems were considered and it has been decided that the following measures will be applied.

- Pavement structure

The pavement structure will be such that the surface course is made of dense graded asphalt mixtures 60 mm thick and the binder course is made of drainage asphalt mixtures 40 mm thick. In order to ensure durability in the midst of heavy aircraft loads, 60 mm is required as the thickness of the surface course. Tack coat using polymer modified asphalt is also required on both the binder course and concrete slabs to secure the bonding strength at the interfaces.

- Water draining facilities

Two kinds of water drainage facilities are built into concrete slabs around the rehabilitation area. One is transverse open grooves 6–10 mm in width to drain out water transversely and encourage evaporation, and the other is wider ditches filled with a drainage asphalt mixture to mainly drain out water longitudinally.

- Asphalt mixtures

For the surface course, dense graded asphalt mixture with polymer modified asphalt (Type II) and aggregates with a 20 mm maximum particle size are used. New specifications on the amount of air voids (4.5%) and dynamic stability (3,000 times/mm) are added. For the binder course, drainage asphalt mixture with polymer modified asphalt (Type H) and aggregates with a 13 mm maximum particle size are used. New specifications on the amount of air voids (20%) and dynamic stability (3,000 times/mm) are added.

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